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Piezoelectric Effect in Dentin

ABRAHAM R. LIBOFF and MORRIS H. SHAMOS

Biophysics Research Laboratory Department of Physics, New York University, New York, New York 10003, USA

It was reported recently (J. M. MUMFORD and A. V. NEWTON, *J Dent Res* 48:226-229, 1969) that there is considerable transduction of mechanical force to electric potential in whole teeth. In the same paper, a tentative model for this phenomenon was presented, which involved the streaming potential in capillaries (the periprocessal space in dentinal tubules). An alternate explanation for this effect, namely, the piezoelectric response of dentin is possible. Piezoelectricity, long regarded as a classical phenomenon in physics (W. G. Cady, *Piezoelectricity*, 1964) has, in the last few years, been found in a variety of biologic materials (V. A. BAZHENOV, *Piezoelectric Properties of Wood*, 1961; M. H. SHAMOS, and L. S. LAVINE, *Clin Orthop* 35:177-188, 1964; E. FUKADA, *Biorheology* (Oxford) 5:199-208, 1968) and it must be recognized as a fundamental property of biologic tissues (M. H. SHAMOS and L. S. LAVINE, *Nature* 213:267-269, 1967). This and other groups have previously reported (SHAMOS, LAVINE, 1964; M. BRADEN ET AL, *Nature* 212:1565-1566, 1966; G. V. B. COCHRAN, R. J. PAWLUK, and C. A. L. BASSETT, *Arch Oral Biol* 12:917-920, 1967) a decided piezoelectric effect in human dentin. However, these were qualitative results and were difficult to interpret because of the specimen size available from humans. A recent determination has been made on horse dentin cubes cut so the dentinal tubules were all approximately parallel.

The expression governing the electric polarization, P_i (coulombs/m²), resulting from the application of stress, S_j (newtons/m²), is $P_i = d_{ij}S_j$, where the 18 elements (d_{ij}) are referred to as the piezoelectric moduli. The index j takes on the values 1 → 6, corresponding to the six possible stresses on a cube, and the index i takes on the values 1, 2, 3, corresponding to the three Cartesian directions.

Depending on the crystal system, most of the d_{ij} are zero. It is generally agreed that the greatest piezoresponse in collagenous systems occurs when the symmetry axis (osteons, tubules, fibrils) is under shear stress, corresponding to the modulus d_{14} . However, the particular experimental model used by Mumford and Newton cannot be interpreted readily in terms

of shear stress on dentinal tubules. Rather, it appears to correspond roughly to the modulus d_{33} , for which there is compressive stress directed along the tubules and for which a potential difference is established between opposite ends of the tubules. Although we have measured only d_{14} in dentin, it is reasonable to expect that d_{33} will be approximately 20 to 25 times smaller, since we have observed this separately in bone and tendon. Thus, for dentin, $d_{33} \sim 0.08/25 = 0.003$ picocoulombs/newton.

The voltage developed by a charge accumulation (Q) across a capacitance (C) is $V = Q/C$. If we assume the simplest dielectric system for the tooth, that of a right circular cylinder of length (l), area (A), and dielectric constant, (k), the capacitance is $C = \epsilon A/l$. This enables us to calculate the expected potential difference for the model in the work by Mumford and Newton, substituting $l = 2 \times 10^{-3}m$, and $A \approx 6 \times 10^{-6}m^2$ for the dimensions. The magnitude of l is chosen as the approximate distance from the end of the pulp cavity to the exposed dentinal surface, and the cross-sectional area is chosen arbitrarily to correspond to that point where the pulp cavity ends. It has been established (J. FRIEDMAN and A. GRAYSON, *Electrical Properties of Tooth Structure*, Conference on Engineering in Medicine and Biology, Washington, DC, November 15-19, 1970) that for dentin, the dielectric constant is 8.60. Inasmuch as the teeth in Mumford and Newton's experiment were moist, the effective dielectric constant was probably somewhat higher; we estimate this magnitude to be ~ 10 . This results in an effective capacitance for Mumford and Newton's model tooth of ~ 0.3 picofarads. We may thus estimate directly the charge resulting from the compressive stress quoted by Mumford and Newton, 2 kg/cm^2 , ($S_3 = 2 \times 10^5 N/m^2$). We find $V = Q/C = P_3 A/C = d_{33} S_3 A/C = 0.003 \times 10^{-12} \times 2 \times 10^5 \times 6 \times 10^{-6} / 0.3 \times 10^{-12} \approx 10 \text{ mv}$. This value is approximately three times larger than the estimate of the streaming potential by Mumford and Newton. Our conclusion is that the magnitude of pressures used in this experiment will result in a potential difference caused by the piezoelectric effect. That our calculation also results in a larger value of voltage than observed, undoubtedly reflects the coarse assumptions used for the dimensions and for the capacitance and for those surrounding our use of the d_{33} modulus. Nevertheless, it seems clear that one can invoke a piezoelectric explanation for the effects observed by Mumford and Newton.

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Additional information available on request to authors.

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